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Mr. Furstenberg is chairman of the Cellular Phone Taskforce, a citizens' group concerned about adverse health effects from telecommunication signal irradiation. He writes that he was electrically injured in 1981 after having attended 3 years of medical school. He states he has been studying and writing about electromagnetic radiation for 15 years.
114. "Information on Human Exposure to Radiofrequency Fields From Cellular Radio Transmitters," Federal Communications Commission, Office of Engineering and Technologic, December 1994
115. "Mobile Satellite Services" in Chapter 3 of: Wireless Technologies and the National Information Infrastructure, Office of Technology Assessment, Congress of the United States, July 1995, OTA-ITC-622, pg. 78-81
116. "Satellite Systems and Services," in Survey of Rural Information Infrastructure Technologies, National Telecommunications and Information Administration, September 1995, NTIA Special Publication 95-33, pg. 4-56 to 4-53
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Power Density W/m = $(3\ \text{V/m})^2 / 377 = 0.024$ W/m or = 2.4 microwatts/sq. cm.

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Power Density W/m = $(3\ V/m)^2/377 = 0.024$ W/m or = 2.4 microwatts/sq. cm.

and Power Density in microwatts/sq. cm = $(V/m)^2$ /3.77, or 9/3.77 = 2.4 microwatts/sq. cm.

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120. Jon Short, of BT Laboratories, Martlesham Heath, Ipswich, England, "EMC Considerations For Digital Cellular Radio and Hearing Aids," COST 219, June 16, 1992 in Dublin. COST means Cooperation Europeenne dans le domaine de la recherche Scientifique ie Technique (European Cooperation in the field of scientific and technical research,

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124. See Ad-Hoc Assn. FCC 96-326 Petition at footnote #48. The Szmigielski studies are described in footnote 84 of the Ad-Hoc Assn. FCC 96-326 Petition, and at 126 below. Also, the source for this quote is:
Current Status: Microwaves and Cancer, A Summary Prepared by the Radiation Biology Branch, CDRH (Center for Device and Radiological Health), FDA (Food and Drug Administration)," in Appendix 5 of Potential Public Health Risks From Wireless Technology: Research Agenda for the Development of Data for Science Based Decision Making," released August 1995, by Scientific Advisory Group on Cellular Telephone Research (now Wireless Technology Research, LTD), 1711 N. Street, Suite 200,Washington D.C tel: (202) 833-2800, fax: (202) 833-2801

125 University of Washington study is footnote #111 of the Ad-Hoc Assn. FCC 96-326 Petition. The source reference is: C.K. Chou, A.W. Guy et al, "Long Term, Low-Level Microwave Irradiation of Rats," Bioelectromagnetics 13:469-496(1992)

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130. C.K.Chou et al, "Effects of Long-term Radiofrequency Radiation on Immunological Competence and Metabolism, USAFSAM-TR-85-105, May 1986.

131. FCC 96-326, Appendix A: Final Regulatory Flexibility Analysis, IV: Summary of Projected Reporting, Recordkeeping and other compliance requirements, pg. 78.

132. Letters of Dr. Mays Swicord, then of the FDA, Center for Device and Radiological Health, and of Dr. M.R. Altman, also of this unit. Their letters are in the records the Institute of Electrical and Electronic Engineers regarding the for IEEE project C95.1, SCC-289 Balloting Committee, with the committee ballot dated May 14, 1991. These letters were included as part of the Exhibits in the Ad-Hoc Association FCC 96-326 Petition.

133. H. Wachtel et al, "Effects of Low-Intensity Microwaves On Isolated Neurons," Annals of the New York Academy of Sciences, Vol. 247,pp. 46-62, 1975.
134. FCC 96-326, para. #28
135. Letter from L.J.Gill of the Food and Drug Administration, Center for Device and Radiological Health, to the FCC, dated November 10, 1993 regardeing ET Docket 93-62
136. Letter from R. W. Niemier of the National Institute of Occupational Safety and Health (NIOSH) to the FCC , dated January 11, 1994, regarding ET Docket 93-62
137. The need for the Commission to state protections provided is requested by the Ad-Hoc Association FCC 96-326 Petition at item #20 on page 16.
138. Letters of Commission Chairman Reed E. Hundt to Carol M. Browner of EPA dated July 1, 1996, to D. Burlington of FDA on July 2, 1996, to Dr. Linda Rosenstock of NIOSH on July 2, 1996, and to J. Dear of OSHA dated July 2, 1996.
139. Occupational Safety and Health Administration (OSHA) letter dated March 1, 1993 to the FCC from Stephen Mallinger, regarding proposed FCC RF guidelines in ET-Docket 93-62
140. Nov. 9, 1993 letter of M.Oge, EPA Director of the Office of Radiation and Indoor Air, to the Commission regarding ET-Docket 93-62
141. L. Salford et al. "Permeability of the blood brain barrier induced by 915 MHz electromagnetic radiation, continuous wave and modulated at 8, 16, 50, and 200 Hz," Microscopy Research and Technique, Vol 27, pg. 535-542, 1994.
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143. O.P.Gandhi, "SAR and Induced Current Distribution in Anatomically Based Models of a Human for Plane-Wave Exposures at Frequencies 20-915 MHz," published under Department of the Army, contract DAMD17-90-M-SA49, U.S. Army Medical Research and Materiel Command, Fort Detrick, Frederick, MD 21702-5012.
144. Q. Balzano and N.Kuster, "Experimental and numerical dosimetry," in Mobile Communications Safety, ed. N.Kuster, Q.Balzano, J.C. Lin, Chapman and Hall, London/New York, 1997, pg. 13-64, quote from page 16.
145 See Ad-Hoc Association FCC 96-326 Petition dated September 6, 1996 at page 14, Reply Comments of Oct. 28, item 4 on page 7, item 2.1.3 on pages 8-11 of Petition for Reconsideration of FCC 96-487, February, 21, 1997. Note: see correction at item 23.3 herein this ex parte presentation.
146. See David Fichtenberg Comments of Oct. 8, 1996 on Petition of the Cellular Phone Taskforce, pages 8-10.
147. D. Hill, "The Effect of Frequency and Grounding on Whole-Body Absorption of Humans in E-Polarized Radiofrequency Fields," Bioelectromagnetics, 5: 131-146, 1984. Note. This paper was selected as a Final List Paper Reviewed for IEEE C99.1-1991
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150. O.P. Gandhi, "d'Arsonval Medal Address: Some Bioelectromagnetics Research at the University of Utah: Acceptance Speech on the Occasion of Receiving the d'Arsonval Medal," Bioelectromagnetics: Vol 17, pg. 3-9, 1996.

151. "Assessment of the Possible Health Effects of Ground Wave Emergency Network," National Research Council, published by National Academy Press, Washington D.C. 1993.
152. FCC 96-326, para. #70
153. Q. Balzano and N.Kuster, "Experimental and numerical dosimetry," in Mobile Communications Safety, ed. N.Kuster, Q.Balzano, J.C. Lin, Chapman and Hall, London/New York, 1997, pg. 13-64, quote from page 50.
154. See footnote 83, section 5. Explanation (on page 21 of standard). The paper referenced was #B26 which is: O.P. Gandhi, "Advances in Dosimetry of Radio-frequency Radiation and their Past and Projected Impact on the Safety Standards," Proceedings of IMTC Instrumentation and Measurement Technology Conference, April 20-22, 1988, San Diego, CA, pp. 109-113, 1988.
155. Johnson, C.C and A.W.Guy, "Nonionizing Electromagnetic Wave Effects in Biological Materials and Systems," Proceedings of the IEEE, Vol 60, pp. 692-718, 1972.
156. Two papers by O.P. Gandhi, submitted for publication to IEEE Transactions on Electromagnetic Compatibility:
1) "Induced Foot Currents in Humans Exposed to Radio-frequency EM Fields"
2) "Electromagnetic Absorption in the Human Head For a Proposed 6 Hz Handset"
both make use the tissue characteristics parameters given in footnote #155 and which are used to derive the results of papers in footnote 142, 143.
157. FCC 96-326, para. #146 and footnote 189.
158. See footnote 34, pages 6.4 to 6.10 to see the SAR for different frequencies for different size humans, form year old infants to adult men.
159. O.P Gandhi et al. "Deposition of Electromagnetic Energy in Animals and in Models of Man with and without Grounding and Reflector Effects," Radio Science,Vol 12(6S):39-47, 1977. Also used and referenced by the U.S. EPA at page 3-12 of footnote #15, thereby indicating that EPA found the analysis valid.
160. Ad-Hoc Association FCC 96-326 Petition at item #10, pages 7-8, and footnote 46 therein.
161 NCRP (1986), :Biological Effects and Exposure Criteria For Radiofrequency Electromagnetic Fields, National Council of Radiation Protection and Measurements, Bethesda Maryland, 20814.
162. C.K. Chou, A.W. Guy et al, "Long Term, Low-Level Microwave Irradiation of Rats," Bioelectromagnetics 13:469-496(1992)
163. H.Lai, A.W. Guy, A. Horita, (1994), "Microwave Irradiation Affects Radial -Arm Maze Performance in the Rat," Bioelectromagnetics 15:95-104
164. Dr. H. Lai and Dr. A. W. Guy (see footnote #163) were both members of IEEE Subcommittee IV on Safety Levels With Respect to Human Exposure, 3 kHz to 300 GHz, of IEEE Standards Coordinating Committee 28. Dr. A. W. Guy was also Chairman of NCRP 1986 (see footnote 161), and Vice Chair of the balloting committee that approved IEEE C95.1-1991.
165. See Ad-Hoc Association FCC 96-326 Petition at items 14.3.5 at page 11, and footnotes 131, 133 discussed at page 16, and item 2.1.2 at page 8 of the Ad-Hoc Association FCC 96-487 petition in ET-Docket 93-62.
166. See Ad-Hoc Association FCC 96-326 Petition at items 14.3.1 to 14.3.6 at page 10-11, and and item 2.1.1 at pages 6-7 of the Ad-Hoc Association FCC 96-487 petition in ET-Docket 93-62, and items 5.1.1 to 5.1.7 on page 20 of the Ad-Hoc Association ex parte submission in this proceeding dated June 10, 1997.
167. Environmental Protection Agency letter from Margo Oge dated November 9, 1993 to Thomas Stanley, Chief Engineer of the Federal Communications Commisson regarding ET Docket 93-62.

168. See pages 185-187 and 189 in footnote 161. For SAR values see pages 5-62, 5-63 in footnote 15.
169. O.P. Gandhi, "The ANSI Radiofrequency Safety Guideline: Its Rationale and Some Problems," in Biological Effects of Electropollution: Brain Tumors and Experimental Models, ed. S.K. Dutta and R.M. Millis, published by Information Ventures, Philadelphia, PA, 1986, Chapter 2, pg. 9-19
170. O.P. Gandhi, "Advances in Dosimetry of Radio-frequency Radiation and their Past and Projected Impact on the Safety Standards," Proceedings of IMTC Instrumentation and Measurement Technology Conference, April 20-22, 1988, San Diego, CA, pp. 109-113, 1988
171. O.P. Gandhi, "ANSI Radiofrequency Safety Guide: Its Rationale, Some Problems, and Suggested Improvements," in Biological Effects and Medical Applications of Electromagnetic Energy, ed. by O.P. Gandhi, published by Prentice Hall, Englewood Cliffs, New Jerey, 1990, Chapter 3, pg. 28-46.
172. See formulas in footnote 118 where the formula for Power density in microwatts / sq. cml = (Electric Field in V/m)^2 / 3.77. This formula can also be verified by applying the formula to the NCRP 1986 limits and to the ANSI/IEEE C95.1-1992 limits given in FCC 96-326 (after allowing for some variance due to rounding-off .
173a. See Ad-Hoc Association FCC 96-326 petition at footnote 133
173b See ex parte June 10, 1997 submission at page 22 item #5.4 and footnote 33 therein.
174. Letter of August 2, 1996 from Gegory J. Baxter, Acting Director, Directorate of Technical Support, Occupational Safety and Health Administration to Mr. Richard Smith, Chief Office of Engineering and Technology, FCC regarding new approach of FCC to RF safety in ET-Docket 93-62
175. Letter of July 25, 1996 from Dr. Paul Schulte, Director, Education and Information Division, National Institute of Occupational Safety and Health, to Mr. Richard Smith, Chief Office of Engineering and Technology, FCC regarding new approach of FCC to RF safety in ET-Docket 93-62
176. FCC 96-326, 47 CFR 1.1307(b)(1)
177. See Ad-Hoc Association FCC 96-326 Petition at item #7, pg. 5-6.
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179. See page Takishima et al. (1979) page 5-45, and 5-51 of footnote #15.
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181. See Ad-Hoc Association ex parte submission dated June 10, 1997 at items 9.1-9.5, 9.11, 9.12, 10.4.
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183. J.Liburdy et. al., Journal of Pineal Research, 14:89-97, 1993
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185. R .Reiter, "The Pineal Gland and Melatonin Synthesis: Their Responses to Manipulations of Static Magnetic Fields", Chapter 11 in, Biological Effects of Electric and Magnetic Fields, Academic Press, New York, 1994, Volume 1, pg.261-286.

186. R. G. Stevens, "Electric Power and Risk of Hormone-Related Cancerns", Vol. 2. Chapter 12 in, Biological Effects of Electric and Magnetic Fields, Academic Press, New York, 1994, pg.263-278.
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192. Smith, A, "Attenuation of Electric Fields and Magnetic Fields by Buildings", IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-20, No.3, August 1978. page 411-418). This research studied RF attenuation for frequencies from 20 kHz to 500 MHz. For one wood exterior residence, after 50 kHz, the attenuation decreased "monotomically to zero at 500 MHz."(page 416).
193. NTIA Report 94-306, 1994, "Building Penetration Loss Measurements at 900 MHz, 11.4 GHz, and 28.8 GHz, by K.C. Allen, N.DeMinco, J.R. Hoffman, Y.Lo, P.B. Papazian, published by the National Telecommunications and Information Administration, U.S. Dept. of Commerce, NTIA Report 94-306, May 1994, National Technical Information Service, NTIS, #PB 94204781
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212. M.Battalora, et al. "The effects of calcium antagonists on anthrone skin tumor promotion and promoter-related effects in SENCAR mice," Cancer Letters, (1995) Vol. 98, pg. 19-25.
213. Z.Davanipour et al. "Amyotrophic Lateral Sclerosis and Occupational Exposure to electromagnetic fields," Bioelectromagnetics, Vol. 18, pg. 28-35
214. P.A. Kondra et al., "Growth and Reproduction of chickens subjected to microwave radiation," Canadian Journal of Animal Science, Vol. 50, 639-644 (Dec. 1970).
215. L.von Klitzing, "Low-Frequency pulsed electromagnetic fields influence EEG of man," Physica Medica, Vol. 11, No. 2, April-June 1995.
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224. "Mobile Satellite Services" in Chapter 3 of: Wireless Technologies and the National Information Infrastructure, Office of Technology Assessment, Congress of the United States, July 1995, OTA-ITC-622, pg. 78-81, 122, 165-166.
225. US West/NewVector Group, "The Basics of Cellular", booklet #M-15-C, June 1994.

40. Conclusions: There are many significant ways in which the Commission's RF rules need to be changed. The federal health agencies have likely overlooked, misunderstood, or were not aware of new information presented by the Ad-Hoc Association and other parties in this proceeding. The Commission should seek federal health agencies to evaluate the RF health claims made in this proceeding, since the Commission does not have expertise in this area, but is nevertheless responsible that its limits be properly protective. Please contact me if the Commission or any reviewing this document are unable to find referenced materials or have questions.

41. Signature:

Respectfully Submitted,

David Fichtenberg

David Fichtenberg Dated: June 30, 1997
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2

Experimental and numerical dosimetry

Niels Kuster and Quirino Balzano

2.1 INTRODUCTION

The objective of this chapter is to document the state of the art of experimental and numerical dosimetry with emphasis on those aspects relevant to mobile communications. This includes the evaluation of the suitability of various tools developed for dosimetry in the frequency range of mobile communications (40 MHz – 6 GHz). Since the suitability of a tool is here determined by the physical requirements defined by the specific applications, the dose rate, the energy absorption mechanism and the two major application areas are discussed first.

2.2 DOSE RATE AND SAFETY STANDARDS

In 1982 the American National Standards Institute (ANSI) became the first organization to introduce the *Dosimetric Concept* for protection from nonionizing radiation (ANSI, 1982) . This represented a marked improvement, since all previous standards, e.g. the ANSI Standard of 1974, were based strictly upon exposure quantities, such as power densities and field strengths. This new approach was subsequently adopted by most national and international standards commissions, e.g. DIN/VDE (1984), NCRP (1986), NRPB (1986), IRPA (1988), TTC/MPT (1990), CENELEC (1995).

The dosimetric concept was initially developed for and successfully applied to protection from ionizing radiation. The ionizing standard is based on an established correlation between the dose and the biological effects, whereby the 'dose' is defined as the energy absorbed per unit mass. Derived values, such as the incident radiation in terms of radiometric quantities, and the definition of dosimetric terms, such as whole body and organ dose, population dose, and relative biological effectiveness, were also defined.

Although this is quite a straightforward approach for protection from ionizing

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considerable technical resources. Hence, as in the field of ionizing radiation, exposure limits had to be derived to achieve a workable standard.

2.2.2 Exposure limits

Exposure limits must have a direct relation to the dose, preferably being proportional. However, in contrast to ionizing radiation, the relationship between the exposure and the induced dose or SAR distribution is significantly dependent on various exposure parameters, such as the frequency and field polarization, as well as on the exposed biological bodies. The human body has complex surfaces and internal geometries and is composed of tissues with spatially varying dielectric properties. Furthermore, the mere presence of the body significantly alters the field distribution. In the case of near field exposures, the coupling between the body and the electromagnetic source can even alter the performance of the source.

Consequently, exposure limits are possible only if they are based on worst case conditions, i.e. when they ensure that the basic limits are satisfied under all conditions. Absorption under various exposure conditions was extensively investigated in numerous studies in the late 70s. From these studies the current exposure limits for electric and magnetic field strengths have been derived. These field quantities can be easily measured using existing equipment (IEEE, 1992). The gist of these studies was that the most efficient absorption occurs under plane wave conditions with an upright human body parallel to the incident E-field. Other, more unusual body postures might also result in enhanced absorption. However, for most body postures other than the upright with parallel field polarization, the derived limits substantially overestimate the actual absorption. This is especially true when the body or body parts are in the close near field of the radiation source and re-radiating structures. For example, in the closest vicinity of low power transmitters, these exposure limits are easily exceeded, although the actual induced absorption might only be a small fraction of the SAR limits.

In other words, the exposure limits are of no use for the safety assessment of handheld telephones. Subsequently, the testing of compliance of handheld mobile communication transceivers with safety limits has lately become the key problem in the area of dosimetry. In view of the importance of this issue, the focus of this chapter will be on the discussion of methods and procedures to assess the basic dose for current standards, i.e. the SAR distribution inside biological tissues. However, one should keep in mind that the importance of time-averaged and volume-averaged SAR values as the only physical quantities of biological relevance is still frequently questioned. The implications of this consideration will be discussed in the following chapters. Even if another measurable quantity proves to be more suitable in future, the following discussions would still be largely applicable.

2.2.3 Exclusions for mobile telecommunications equipment

Right from the onset of the development of the dosimetric concept, it became obvious that handheld mobile telecommunications equipment (MTE) would exceed the derived safety limits. ANSI C95.1-1982 (ANSI, 1982) simply bypassed this problem by an exclusionary clause for low power handheld devices. In this clause all transceivers operating below 1 GHz and radiating less than 7 W were excluded from the requirement to demonstrate compliance with the basic safety limits. This exclusionary clause was adopted worldwide by most standard-setting organizations, although there was no real scientific back-up for this assumption. It was dropped or modified in the beginning of the 90s, when it became well known that transceivers with an input power of 7 W may result in spatial peak SAR values of well above 100 mW/g (Kuster, 1992a; Meier *et al.*, 1996a). However, the 7 W exclusion, together with an extended frequency range of up to 3 GHz, is still valid in some national standards (e.g. Sweden and Japan).

The scientific data available in the early 80s and used to substantiate this exclusion were from experimental studies that had been performed on various transmitters operating at frequencies between 30 and 900 MHz (Balzano *et al.*, 1977; 1978a; 1978b). However, they did not supply any supporting evidence of the soundness of the 7 W exclusion clause.

During the eighties the absorption induced by sources in the close vicinity of biological bodies were studied in several laboratories (Chatterjee *et al.*, 1985; Guy and Chou, 1986; Stuchly *et al.*, 1986a; 1986b; 1987; Kuster and Ballisti, 1989; Cleveland and Athey, 1989; Fujiwara *et al.*, 1990). The results proved to be difficult to interpret and contradictory with respect to the conclusions about the validity of the exclusionary clause. A study in 1992 on the absorption mechanism of biological bodies in the near field of dipole sources clarified the situation and showed conclusively that the exclusionary clause is in clear contradiction of the spatial peak SAR limits (Kuster and Balzano, 1992).

These contradictory findings from distinguished research groups demonstrate the difficulties in performing accurate and reliable dosimetric studies, especially in the close near field of sources. This is just as true for the evaluation and design of optimized exposure setups to be used for ***in vitro*** and ***in vivo*** experiments.

It is interesting to note that NCRP (NCRP, 1996), which defined the same basic restrictions in their guidlines as ANSI (ANSI, 1982), did not adopt the 7 W exclusion in 1986. However, it permitted the use of MTE exceeding the limits of the general population as a personal decision by the individual, provided the exposure of the user does not exceed the recommended occupational guidelines and provided that people other than the user are not exposed above the population guidelines. A tighter criterion was added for modulated exposures: 'If the carrier frequency is modulated at a depth of 50 percent or greater at frequencies between 3 and 100 Hz, the exposure criteria for the general population in which γ_{pw} is the plane-wave reflection coefficient for the H_t-field

$$\gamma_{pw} = \frac{2|\sqrt{\epsilon'}|}{|\sqrt{\epsilon'} + \sqrt{\epsilon_0}|} - 1 \tag{2.3}$$

with the complex permittivity $\epsilon' = \epsilon - \sigma/i\omega$. The correction coefficient c_{corr} is introduced to take into account the changed reflection properties from small distances d of the antenna from the scatterer. It was empirically approximated to be:

$$c_{corr} = \begin{cases} 1 & : \quad d \geq 0.08\lambda/\gamma_{pw} \\ \sin(\frac{\pi}{2}\frac{\gamma_{pw}}{0.08}\frac{d}{\lambda}) & : \quad d < 0.08\lambda/\gamma_{pw} \end{cases}$$

Because of the relatively large dimensions of the human head and high conductivity above 800 MHz (dimension with respect to the skin depth δ and wavelength inside the tissue), this approximation is well suited for estimation of the exposure of sources in the vicinity of the head or body. If the H-field can be assessed from the current distribution on the transceiver, the spatial peak SAR averaged over a cube of side length Δx (SAR_{av}) can be approximated for a homogeneous representation of the head by

$$SAR_{av} \approx \frac{\delta_{skin}}{2\Delta x} SAR_s (1 - e^{-\frac{2\Delta x}{\delta_{skin}}}) \tag{2.4}$$

whereby δ_{skin} is the skin depth of the tissue and SAR_s the surface SAR value approximated by (2.2). In many cases it is sufficient to calculate the incident magnetic field ($H^2_{t_{inc}}$) from the assumed current distribution by simple quasi-static considerations.

An analytically based approach for a layered box (corresponding to the head) has recently been published (King, 1995a). The problem of the evaluation for exposure assessments has been transferred to the assessment of the equivalent dipole moment. This paper does, however, confirm the more easily applicable empirical approximation formula (2.4).

For body cross-sections significantly smaller than the wavelength (e.g. small animals), the SAR distribution is similar to induced eddy currents, with high absorption at the peripheral regions and small values in the center. An example is illustrated in the Figures 2.8 and 2.13. Another example is the absorption in Petri-dishes (Burkhardt *et al.*, 1996), where a good approximation could also be obtained by separately considering capacitive and inductive coupling.

In the frequency range below 200 MHz the body is capacitively coupled to the handheld device, which is often operated with electrically short antennas. In this case the body is an integral part of the antenna system and simple antenna models might be useful for dosimetric estimations.

2.3.2 Considerations for nonhomogeneous bodies

The validity of the above discussed energy absorption mechanism has been widely questioned for strongly nonhomogeneous bodies, such as the human head. This has been addressed recently in two studies about the dependence of electromagnetic energy absorption upon human head modeling for the frequency range below 900 MHz (Hombach *et al.*, 1996) and for 1.8 GHz (Meier *et al.*, 1997). The studies have been conducted using several numerical and experimental phantoms. Phantoms in the context of this chapter are physical or numerical bodies which simulate the electrical properties of living biological bodies. They can be of varied complexity with respect to tissue composition as well as to shape. The most complex phantoms used in this study of the absorption dependence upon modeling were three independently discretized head phantoms based on MRI scans of three different adults, whereby 13 different tissue types were distinguished. One of them is shown in Figure 2.1. The most simple phantom was a homogeneous sphere of 200 mm diameter. The findings of these studies can be summarized as follows:

- The global SAR distribution is similar for homogeneous and nonhomogeneous modeling, i.e. the energy absorption mechanism is not changed (Figure 2.2). In other words, the absorption distribution is strongly related to the expected incident magnetic field, i.e. to the RF current distribution versus the distance. Most of the power is absorbed close to the radiating structure and focusing effects are negligible.
- The local SAR distribution depends significantly on the local distribution of the electrical tissue properties. In humans, however, the local tissue distribution for various individuals varies largely and can even change with time. For example, the outer shape depends on the individual profile and on any movement of the mouth or the eyes. The electric parameters of a human body vary with levels of physical and metabolic activity, health, and age.
- The spatial peak SAR values also depend on the local anatomy. On the other hand, the homogeneous modeling led to results which also overestimated the values of the nonhomogeneous head with the highest absorption. However, the overestimation is surprisingly small for the site above the ear, i.e. <10% for the 10 g averaged values and <25% for the 1 g averaged values .
- Small shifts (<10 mm) of the source parallel to the surface of body can result in variations of the spatial peak SAR of larger 3 dB in the case of nonhomogeneous modeling. For homogeneous bodies such shifts do not lead to any changes in the spatial peak SAR values, which always overestimate the values of the nonhomogeneous case.
- The effects due to the shape of the head are negligible for a given distance of the RF current source from the body.
- The human hand is an anatomically and geometrically complex structure which can cover an MTE in almost an infinite number of configurations.

restrictions can also be demonstrated by directly determining the SAR distribution in experimental or numerical phantoms representing the human body. Such dosimetric assessments, however, are generally difficult to perform, especially because the body may strongly interact with the radiation source or the reradiating structures nearby. The absorption depends on various parameters, such as the position of the RF source near the body, posture, size and anatomy. In addition, possible error sources in the experimental and numerical dosimetry are numerous. Testing compliance with the basic restrictions is therefore time consuming and expensive and should be considered as a solution of last resort.

The easiest way to enforce safety limits is to implement appropriate measures to prevent access to critical areas where the exposure limits are exceeded. If access is required under certain circumstances (e.g. for maintenance purposes), the operator of the installation can stipulate a procedure (e.g. shutdown of the transmitter or wearing of protective clothing), to avoid exposure exceeding the safety limits.

Some equipment, however, need to be operated in the close vicinity of users for functional reasons (e.g. portable and handheld MTE). Exclusionary clauses can be defined but should satisfy the worst case criteria. This may not be the case for the exclusionary clause for low power devices defined in ANSI C95.1-1992 (ANSI, 1992). A better basis to define a sound exclusionary clause might be the approximation formula (2.4). However, further studies are needed to verify its general validity and its range of uncertainty.

However, many cellular phone systems do not fall under such an exclusion, since their maximum input power is large enough to theoretically exceed the spatial peak SAR limits. This has the consequence that a special procedure must be implemented to demonstrate compliance with basic restrictions. Since this is one of the key problems in the dosimetry of mobile communications, special requirements for compliance testing of handheld MTE are necessary and are discussed in the following Section 2.5.

2.5 SPECIAL REQUIREMENTS FOR COMPLIANCE TESTING OF MTE

2.5.1 Introduction

In recent years handheld mobile telecommunication equipment (MTE) have become a common and widely used consumer product. Their use is shifting from mainly business oriented to personal. With falling operational costs more frequent and more prolonged conversations can be expected (see also Chapter 1). However, the operation of transmitters in very close proximity to the head subjects the exposed parts of the user's body to electromagnetic fields which are several magnitudes above the average background fields. The locally induced

field strength is significantly higher than any exposure the broader public has been exposed to before, except during certain common medical treatments (e.g. MRI, diathermy, hyperthermia, etc). Recent studies have even shown that some current cellular phones are close to or even exceed recommended limits under certain operational conditions (Meier *et al.*, 1995).

In view of this, it is reasonable that some health agencies are urgently calling for dosimetric type approval and require compliance with safety limits under all operational conditions (Strahlenschutzkommission, 1992; Bundesamt für Gesundheit, 1993). Such a worst case approach is directly analogous to the commonly applied safety considerations for chemical and physical agents. Some manufacturers and service providers, on the other hand, prefer to test under intended use or normal positions only, a position which is described in their user manuals. This is because of their concern that more strict requirements cannot be satisfied with current technology, especially in view of the consumer's desire to purchase smaller and lighter devices. It is clear that desired growth can only be realized with an attractive high-tech consumer product.

The rationale is often brought up that since large safety factors have been incorporated in the standards, exceeding these limits under certain circumstances is acceptable. However, this argument is contradictory to the basic idea of safety standards, since these factors consider the uncertainty of the extrapolation from animal experiments to the human organism. In addition, they should also incorporate possible variations among humans with respect to their biological responses on physical stimulus. It would therefore not be consistent to apply them for the uncertainty of the exposure as well.

Other arguments are that it is unlikely that a user would hold the device in the same position during the entire averaging period (see Table 2.1) or that the device would be continually radiating at maximum power during the entire averaging period. Power levels of the devices undergo constant adjustment according to radiation conditions. Furthermore, when the discontinuous transmission mode (DTX) is used, the averaging power level is reduced according to the talk-listening ratio. These combined improbabilities might justify less rigid test requirements than those initially requested by some health agencies.

On the other hand, intended or normal positions do not reflect the actual average use. Hence, the exposure assessment under this intended use position would differ from those of many daily life situations, since tests have shown (Meier and Kuster, 1995) that this position results in spatial peak SAR levels which are close to the minimum among the various operational positions.

Considering all these aspects, a certification procedure could only be considered to be sound if it satisfy the following basic requirements.

2.5.2 Basic requirements

- The procedure should ensure that the assessed spatial peak SAR values do